ASSESSMENT OF THE ENERGY PRODUCTION OF THE PROPOSED HEPBURN COMMUNITY WIND PARK

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A	16th Nov 2007	First issue
B	21st Nov 2007	Revised issue with 69 m hub height
C	7th May 2008	FINAL

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1 INTRODUCTION

This report has been prepared pursuant to the GH Proposal Reference P564/PP/01 dated 10th September 2007, and is subject to the terms and conditions contained therein.

Future Energy Pty Ltd (FE) has commissioned Garrad Hassan (GH) to carry out an independent assessment of the wind climate and expected energy production of the proposed Hepburn Community Wind Park. The results of the work are reported here.

A description of the long-term wind climate at a potential wind farm is best determined using wind data recorded at the site. FE has supplied GH with one year of data recorded at the Hepburn Community Wind Park site.

When a long period of site data is not available, it is usual to combine the site measurements with long-term measurements from a local meteorological station. GH has obtained data from four Bureau of Meteorology (BoM) reference masts. These data have been used to assess the long-term regional wind climate.

The proposed layout and turbine models currently under consideration have been supplied by FE. The proposed layout consists of 2 turbines. The layout has been used in conjunction with the results of the wind analysis, to predict the long-term energy output of the proposed wind farm.

2 DESCRIPTION OF THE SITE AND MONITORING EQUIPMENT

2.1 The site

The site is located approximately 10 km south of the township of Hepburn Springs in central Victoria, as shown in Figure 2.1. Also shown in this figure is the location of some of the meteorological stations which have been considered as sources of long-term wind data in the assessment of the site wind regime.

The proposed wind farm contains two turbines on a rounded hill-top approximately 740 m above sea level. The Daylesford mast is located just to the west of the turbines at an elevation of 740 m. There are practically no steep slopes in excess of 17 degrees in the vicinity of the proposed wind farm. The general terrain at the site is described as moderately complex.

The site and surrounding area consists mainly of farm land with large areas of dense trees to the west and east of the site.

A more detailed map is presented in Figure 2.2, which also shows the location of the anemometry mast and turbines.

The surface roughness length of the site and surrounding area was approximated from maps of the area. No site visit has been made by GH staff. Following the Davenport classification [2.1], the following general figures are considered appropriate:

Water	0.00 m
Farmland	0.03 m
Trees	0.5 m

2.2 Monitoring equipment

Details of the measurements recorded on site and the grid co-ordinates of each of the masts used in the analysis are presented in Table 2.1.

The Daylesford 50 m mast is a guyed tubular Jennings mast of diameter 150 mm. The wind data have been recorded using RISO type P2546A anemometers and Vector W200P wind vanes throughout.

Records for the site measurements have been provided. The standard of documentation is good and sufficient to ensure full traceability of the instrumentation.

Instruments mounted on the Daylesford mast include a top-mounted anemometer at 51.7 m and a boom-mounted anemometer at 20 m pointing to 261˚. Wind vanes are mounted at 51.2 m and 20 m.

The top mounted anemometer is positioned on a vertical boom in excess of 14 mast diameters above the top of the mast. This mounting arrangement is consistent with IEC recommendations [2.2].

The 20 m anemometer is mounted 1.6 m from the mast on a horizontal boom of diameter 42 mm. The cups of the anemometer are in excess of 20 boom diameters above the boom. This mounting arrangement is consistent with IEC recommendations [2.2].

Both anemometers at the site have been calibrated by Svend Ole Hansen ApS at a MEASNET facility in Denmark. Copies of the calibration certificates have been supplied by FE to GH. These individual calibrations have been applied by the data loggers and inspection of the raw scheme file supplied indicates that these have been entered correctly into the logger.

3 SELECTION OF A REFERENCE METEOROLOGICAL STATION

In the assessment of the wind regime at a potential wind farm site it is generally necessary to correlate data recorded on the site with data recorded from a nearby long-term reference meteorological station. Wind data at a site are often only recorded for a short period and such correlation is required to ensure that the estimates of the wind speeds at the site are representative of the long-term. When selecting an appropriate meteorological station for this purpose it is important that it should have good exposure and that data are consistent over the measurement period being considered.

GH has obtained data from the following four meteorological stations located throughout the general region of the wind farm:

- Ballarat
- Stawell
- Laverton
- Sheoaks

Analysis has been conducted to assess the long-term consistency of each of these BoM stations and the results indicate that the AWS stations above are considered to be generally consistent with each other and hence assumed to represent the regional wind regime. These stations are situated between 31 km and 129 km from the site, as illustrated in Figure 2.1.

As discussed further in Section 6, these stations were all correlated to the site and this analysis indicated that the measurements from the Ballarat BoM station give the best representation of the conditions seen at the Daylesford mast.

GH therefore considers the Ballarat BoM station to be the most representative source of reference data available to define the long-term wind conditions at the site. Table 2.1 provides a description of measurements made at the Ballarat Meteorological Station.

4 WIND DATA

The data sets which have been used in the analysis described in the following sections are summarised in Table 2.1.

4.1 Wind data recorded at the site

The wind data have been subject to a quality checking procedure by GH to identify records which were affected by equipment malfunction and other anomalies. The check of the Daylesford mast data at 51.7 m revealed 0 hours of missing data. The check of the Daylesford mast data at 20 m revealed 75 hours of missing or erroneous data. These data were excluded from the analysis. FE has indicated that there were short periods in May 2007 and August 2007 with problems at the 20 m anemometer.

The duration, basic statistics and data coverage for the Daylesford mast data are summarised in Tables 4.1 and 4.2.

4.2 Wind data recorded at the reference station

The wind data have been subject to a quality checking procedure by GH to identify records which were affected by equipment malfunction and other anomalies. The check of the Ballarat data revealed that over the 8.1 years of recorded data, 1,000 hours of wind speed data were found to be missing or suspect. These data were excluded from the analysis.

It is noted that the missing and suspect data were spread throughout the measurement period with most months having data coverage in excess of 90%. This level of data coverage is not considered to be unusual for BoM reference masts.

The duration, basic statistics and data coverage for the Ballarat reference station data are summarised in Table 4.3.

5 DESCRIPTION OF THE PROPOSED WIND FARM

5.1 The wind turbines

Currently two models of turbine are under consideration for the Hepburn Community Wind Park, the REpower MM82 Evolution and the Windtec WT2000sg. The basic parameters of each turbine are presented in Table 5.1.

Using historical pressure and temperature records from nearby meteorological stations and standard lapse rate assumptions, GH has estimated the long-term mean air density at the site to be 1.138kg/m³ at an average hub elevation of 800 m above sea level.

The power curves used in this analysis have been adjusted to the predicted site air density, in accordance with the recommendations of [5.1]. This has been undertaken on an individual turbine basis.

5.1.1 REpower MM82 Evolution

The power curve used in this analysis has been supplied by REpower [5.2] and is presented in Table 5.2. The power curve is for an air density of 1.225 kg/m³, and a turbulence intensity of 6 to 12 %.

The supplied power curve is based on calculations and exhibits a peak power coefficient, Cp, of 0.46. This is considered to be reasonable for a modern wind turbine.

5.1.2 Windtec WT2000sg

The power curve for the Windtec WT2000sg used in this analysis has been supplied by FE [5.3] and is presented in Table 5.2. The power curve is for an air density of 1.225 kg/m³. It is noted that the turbulence intensity has not been specified for this power curve.

The supplied power curve is based on calculations and exhibits a peak power coefficient, Cp, of 0.45. This is considered to be reasonable for a modern wind turbine.

GH understands that no Windtec WT2000sg turbines have been manufactured. There is therefore no track record for this turbine.

5.2 Wind farm layout

The proposed layout currently under consideration has been supplied by FE [5.4] and is shown in Figure 2.2.

The layout consists of 2 turbines aligned approximately west-northwest – east-southeast. The grid references of the turbines are given in Table 5.4.

It is noted that a 2.7 rotor diameter inter-turbine spacing is proposed in the layout from FE. Even though this separation is not aligned to the most frequent wind directions, the increased turbulence levels will increase fatigue loads. It is also noted that there are some trees close to the turbines. The presence of trees may result in increased turbulence levels and increased shear across the turbine rotor which will increase fatigue loads. It is recommended that the turbine supplier be approached at an early stage to gain approval for the proposed layout.

GH considers that the alignment of the turbines is not optimal when the wind rose for the site (shown in Figure 6.1) is considered. Reduced wake effect and reduced turbulence levels could be achieved by aligning the turbines west-southwest – east-northeast.

6 ANALYSIS AND RESULTS

The analysis of the wind farm involved several steps, which are summarised below:

- The wind speed and direction frequency distribution at the Daylesford mast at 51.7 m height was derived for the period from August 2006 to September 2007.

- A regional assessment of the wind regime was conducted using data recorded at four BoM reference stations. From this it was deemed appropriate to assess the long-term conditions at the site using the Ballarat reference station.

- A monthly correlation was conducted from the Ballarat reference station, thus defining the long-term mean wind speed at the Daylesford mast. An independent check was performed using the Stawell, Sheoaks and Laverton AWSs as references and this confirmed the predicted site wind speeds.

- The measured wind regime at the Daylesford mast was then scaled to represent the long-term wind speed derived above, thus defining the long-term wind regime at the Daylesford mast at 51.7 m.

- An analysis of the measured vertical shear profile was conducted at the Daylesford mast. The measured shear was used to extrapolate the long-term hub height wind speed. The wind regime at the measured height was scaled to represent this wind speed, thus defining the long-term hub height wind regime at the Daylesford mast.

- Wind flow modelling was carried out to determine the hub height wind speed variations over the site relative to the anemometry mast.

- The energy production of the wind farm was calculated for each turbine model taking account of array losses, topographic effects, availability, electrical transmission efficiency, air density effects and other potential losses.

A more complete description of the methods employed is included in the Appendix.

6.1 Measured wind regime at the Daylesford mast at 51.7 m

As detailed in Section 4, wind measurements from the Daylesford mast over a period of approximately one year were available for the analysis. In order to avoid the introduction of bias into the annual mean wind speed estimate from seasonally uneven data coverage, the following procedure was followed:

- The mean frequency distribution for each month was determined from the average of all valid data recorded in that month over the period. This was taken as the monthly mean thereby assuming that the valid data are representative of any missing data.

- The mean of the monthly means was taken to determine the annual mean ("mean of means") to eliminate the effect of seasonal bias in the data.

By this method, as shown in Table 6.1, the measured mean wind speed at the Daylesford mast was found to be 7.4 m/s. The corresponding measured wind speed and direction frequency distribution is presented in Table 6.2 and in Figure 6.1 in the form of a wind rose.

It is observed that the Daylesford mast wind rose has a predominance of winds from the south-southeast and north-northwest.

6.2 Long-term mean wind regime at the Daylesford mast

The correlation to the site and long-term consistency has been tested for each of the potential reference stations described in Section 3. From this, it has been found that the data recorded at the Ballarat reference station is suitable to define the long-term wind regime at the site. The long-term mean wind speed at the Ballarat reference station at 10 m was found to be 5.4 m/s.

Various correlation methodologies were tested on an hourly and monthly basis, resulting in regression coefficients which have been calculated to adjust the site measurements such that they represent the long-term. By this method the long-term predicted mean wind speed at the Daylesford mast was found to be 7.3 m/s.

Similar analysis has been conducted using the Stawell, Laverton and Sheoaks reference stations. These results support the predictions obtained using the Ballarat reference station.

6.3 Vertical shear profile

An assessment of the vertical shear profile using the log law has been undertaken with the site measurements.

As detailed in Section 2, the anemometers at the mast have been calibrated in a MEASNET facility and are mounted in accordance with the recommendations of the IEA. GH therefore considers it appropriate to use the measured shear profile to extrapolate the long-term hub height wind speed at the Daylesford mast.

GH generally recommends that at least three, and preferably four, anemometers are used to calculate the measured shear profile at a mast, therefore giving an indication of the agreement to the log law. There is therefore significant uncertainty in the calculation of the measured shear profile at this site as only two anemometers have been installed at the mast.

The measured frequency distribution at the Daylesford mast, at 51.7 m, has been scaled to represent the predicted long-term hub height wind speed, thus defining the long-term hub height wind regime at the mast. Using this method, the long-term mean wind speed at the Daylesford mast, at a hub height of 69 m, was found to be 7.7 m/s.

6.4 Site wind speed variations

The variation in wind speed over the wind farm site has been predicted using the WAsP computational flow model as described in the Appendix. The wind flow model has been initiated from the long-term mean wind speed and direction frequency distribution derived for the Daylesford mast at hub height.

The wind farm is located within moderately complex terrain but without significant areas of steep slopes. The presence of steep slopes can cause localised separation of the flow. In regions of separated flow it is known that the accuracy of wind flow modelling is poor due to the formation of a separation bubble which reduces the effective slope, as described by Cook [6.1].

For turbine locations with slopes significantly in excess of 17 degrees in the prevailing wind directions, and to a greater extent than at the initiation anemometry mast location, there is a tendency for the WAsP model to overpredict the wind speed and consequently energy production of such turbines. Conversely, if the initiation anemometry mast is located in an area more heavily influenced by slopes in excess of 17 degrees than the turbine locations, there is a tendency for the WAsP model to underpredict the wind speed at such turbines.

A review of the wind farm was therefore undertaken to establish whether such conditions were present. No significant areas of steep slopes were found in the wind farm area.

Due to the close proximity of the monitoring mast to the turbine locations and the lack of steep slopes in the area, GH has assessed the wind farm as a whole and assumed that no net over or under prediction is present.

As detailed in section 2.1, there are areas of trees around the proposed wind farm. The wind flow modelling therefore needs careful consideration. Where there are obstacles to the wind flow, such as buildings or trees, in the vicinity of a wind turbine, it is necessary to include the effect of the obstacles in the wind flow modelling [6.2]. GH considers that the Daylesford mast is sufficiently close to the turbine positions that there is negligible difference between the exposure of the mast and the turbines.

Table 5.4 shows the predicted long-term mean wind speed at each turbine location at hub height. The average long-term mean wind speed for the wind farm as a whole was found to be 7.7 m/s.

6.5 Projected energy production

The energy production of the wind farm is detailed in the table below and definitions of the various loss factors are included in the Appendix. The energy capture of individual turbines is given in Table 5.3.

Turbine Type	**MM82**	**WT2000sg**	
Hub Height	**69**	**69**	**M**
Rated Power	**4.0**	**4.0**	**MW**
Ideal output	13.2	12.5	GWh/annum
Topographic effect	100.4%	100.5%	GH calculated
Wake effect	98.5%	98.2%	GH calculated
Electrical efficiency	97.0%	97.0%	GH assumption
Availability	97.0%	97.0%	GH assumption
Icing and blade degradation	99.5%	99.5%	GH assumption
High wind hysteresis	100.0%	99.4%	GH estimate
Substation maintenance	99.8%	99.8%	Typical value
Utility downtime	100.0%	100.0%	Not considered by GH
Power curve adjustment	100.0%	100.0%	Not considered by GH
Wind sector management	100.0%	100.0%	Assumed not required
Net output	**12.2**	**11.4**	**GWh/annum**

The values for topographic and array effect have been calculated using the methods described in the Appendix.

The table above includes potential sources of energy loss that have been estimated, assumed or not considered. It is recommended that the client consider each of these losses and the possible effect they may have on the wind farm.

6.5 Uncertainty analysis

The main sources of deviation from the central estimate have been quantified and are shown in Table 6.3. The figures in the table are added as independent errors giving the following uncertainties in net energy production for the wind farm. These represent the standard deviation of what is assumed to be a Gaussian process:

	MM82	WT2000sg	
In any one year period	2.2	2.2	GWh/annum
In any ten year period	1.7	1.7	GWh/annum

The uncertainties that have been considered in the analysis include the following:

- Accuracy of the wind measurements;
- Correlation accuracy;
- The assumption that the 12 month period of data available at the site is representative of the long-term wind regime;
- The accuracy of the extrapolation of wind speeds from the mast height to hub height;
- The accuracy of the wind flow modelling;
- The accuracy of the wake modelling;
- The variability of the future annual wind speeds at the site.

There are a number of uncertainties that have not been considered at this stage, including those listed below. It is recommended that the client consider each of these uncertainties carefully. They can often be mitigated to some extent, especially in early years of the project, through appropriate warranty provisions. Therefore these uncertainties should be considered in combination with these provisions, for instance as part of a full technical due diligence exercise.

- Compliance with the assumed power curve;
- Turbine availability;
- Electrical losses;
- High wind hysteresis;
- Icing and blade degradation;
- Substation maintenance;
- Utility downtime.

7 CONCLUSIONS AND RECOMMENDATIONS

Wind data have been recorded at the Hepburn Community Wind Park site for a period of approximately 1.0 year. Based on the results from the analysis of these data the following conclusions are made concerning the site wind regime.

1. The long-term mean wind speed is estimated to be 7.3 m/s at a height of 51.7 m above ground level at the location of the Daylesford mast and 7.7 m/s at the proposed hub height of 69 m.

2. The standard error associated with this prediction of long-term mean wind speed is 0.50 m/s for the Daylesford mast at 69 m. If a normal distribution is assumed, the confidence limits for the predictions are as given in the table below:

Probability of exceedance [%]	**Long-term mean wind speed at 69 m [m/s]**
90	7.0
75	7.3
50	7.7

   Site wind flow and array loss calculations have been carried out and from these we draw the following conclusions:

3. The long-term mean wind speed averaged over 2 turbine locations at hub height is estimated to be 7.7 m/s.

4. The projected energy capture of the proposed wind farm is 12.2 GWh/annum for the MM82 and 11.4 GWh/annum for the WT2000sg. This includes calculation of the topographical, array and air density effects and assumptions or estimates for electrical transmission losses, availability, power curve adjustment, high wind hysteresis, substation maintenance, and the effect of blade fouling or icing.

   There are a number of other losses that could affect the net energy output of the wind farm, as detailed in the Appendix, but these have not been considered here. It is recommended that the client considers each of these losses and the possible effect they may have on the net energy production.

   The net energy prediction presented above represents the long-term mean, 50% exceedance level, for the annual energy production of the wind farm. This value is the best estimate of the long-term mean value to be expected from the project. There is therefore a 50% chance that, even when taken over very long periods, the mean energy production will be less than the value given.

5. The standard error associated with the prediction of energy capture has been calculated and the confidence limits for the prediction are given in the table below :

Probability of Exceedance [%]	**Net energy output [GWh/annum]**			
	1 year average		**10 year average**	
	MM82	WT2000sg	MM82	WT2000sg
90	9.4	8.6	10.1	9.2
75	10.8	9.9	11.1	10.3
50	12.2	11.4	12.2	11.4

   There are a number of uncertainties that have not been considered at this stage, as detailed in Section 6. It is recommended that the client consider each of these uncertainties carefully. They can often be mitigated to some extent, especially in early years of the project, through appropriate warranty provisions. Therefore these uncertainties should be considered in combination with these provisions, for instance as part of a full technical due diligence exercise.

6. It is noted that inter-turbine spacing of 2.7 rotor diameters is proposed. Even though this separation is not aligned to the most frequent wind directions, the increased turbulence levels will increase fatigue loads. It is also noted that there are some trees close to the turbines. The presence of trees may result in increased turbulence levels and increased shear across the turbine rotor which will increase fatigue loads. It is recommended that the turbine supplier be approached at an early stage to gain approval for the proposed layout.

7. GH considers that the alignment of the turbines is not optimal when the wind rose for the site (shown in Figure 6.1) is considered. Reduced wake effect and reduced turbulence levels could be achieved by aligning the turbines west-southwest – east-northeast

8. GH generally recommends that when measurements are not made at or near to hub height, then at least three, and preferably four, anemometers are used to calculate the measured shear profile at a mast, therefore giving an indication of the agreement to the log law. There is therefore significant uncertainty in the calculation of the measured shear profile at this site as only two anemometers have been installed at the Daylesford mast.

9. In complex terrain, GH generally recommends that all proposed turbine locations are within 1 km of a measurement mast which is at least two thirds of the proposed turbine hub height. These conditions are met at the site, and there is therefore only a small uncertainty in predicting the mean wind speed at the turbine locations. Also, given the size of the project, it is not considered critical to do any additional monitoring at higher heights or at other locations.

REFERENCES

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5.4 “Hepburn Wind Energy Analysis”, Email from David Shapero to Graham White, 18 September 2007.

6.1 Cook N J “The Designer’s” guide to wind loading of building structures”, Part 1, Butterworths, 1985.

6.2 I Troen and E L Petersen, “European Wind Atlas”, Risø National Laboratory, Denmark, 1989.

LIST OF TABLES

LIST OF FIGURES

Location	Description of measurements	Period
Daylesford mast (55 H 245259E 5853887N)	Ten minute wind speed and direction recorded at 20 m and 51.7 m height.	Aug 2006 – Sep 2007
Ballarat BoM AWS (Lat: -37.5128 Long: 143.7911)	Ten minute wind speed and direction recorded at the end of each hour at a height of 10 m.	Jul 1999 – Sep 2007

Note: Coordinate system is GDA 94

Table 2.1 Summary of measurements made at the site and Ballarat Meteorological Station

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
Aug-06*	7.3	4.5	4.5
Sep-06	7.3	100.0	100.0
Oct-06	7.2	100.0	100.0
Nov-06	7.8	100.0	100.0
Dec-06	7.6	100.0	100.0
Jan-07	7.5	100.0	100.0
Feb-07	7.3	100.0	100.0
Mar-07	7.8	100.0	100.0
Apr-07	6.1	100.0	100.0
May-07	8.0	100.0	100.0
Jun-07	7.7	100.0	100.0
Jul-07	7.5	100.0	100.0
Aug-07	7.4	100.0	100.0
Sep-07*	7.5	21.5	21.5

* Incomplete month

Table 4.1 Measurements made at the Daylesford mast at a height of 51.7 m

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
Aug-06*	6.1	4.5	4.5
Sep-06	6.1	100.0	100.0
Oct-06	5.9	100.0	100.0
Nov-06	6.4	100.0	100.0
Dec-06	6.3	100.0	100.0
Jan-07	6.3	100.0	100.0
Feb-07	6.0	100.0	100.0
Mar-07	6.4	100.0	100.0
Apr-07	5.0	100.0	100.0
May-07	6.9	89.9	100.0
Jun-07	6.3	100.0	100.0
Jul-07	6.3	100.0	100.0
Aug-07	6.1	100.0	100.0
Sep-07*	6.2	21.5	21.5

* Incomplete month

Table 4.2 Measurements made at the Daylesford mast at a height of 20 m

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
Jul-99*	6.3	49.7	49.7
Aug-99	5.9	70.4	69.9
Sep-99	5.7	100.0	99.3
Oct-99	5.0	100.0	98.7
Nov-99	5.2	100.0	98.9
Dec-99	5.9	99.5	98.8
Jan-00	5.9	99.3	98.8
Feb-00	6.1	100.0	99.3
Mar-00	5.8	100.0	99.1
Apr-00	4.8	100.0	95.0
May-00	5.3	100.0	98.5
Jun-00	5.3	100.0	98.6
Jul-00	5.5	99.5	96.2
Aug-00	4.5	99.2	96.9
Sep-00	6.1	98.9	97.8
Oct-00	5.2	99.7	98.0
Nov-00	5.3	98.3	96.5
Dec-00	5.6	99.2	98.9
Jan-01	6.2	97.6	97.3
Feb-01	6.0	99.7	99.6
Mar-01	5.5	99.3	99.1
Apr-01	5.0	100.0	98.9
May-01	3.8	99.2	93.3
Jun-01	5.4	99.9	98.6
Jul-01	4.6	95.3	93.4
Aug-01	6.0	99.1	98.4
Sep-01	5.4	99.3	95.6
Oct-01	5.5	98.3	97.2
Nov-01	5.4	99.7	99.3
Dec-01	5.5	92.2	91.4
Jan-02	6.0	97.5	97.3
Feb-02	6.0	99.7	99.4
Mar-02	5.7	100.0	99.1
Apr-02	4.7	99.9	99.0
May-02	4.5	91.0	88.0
Jun-02	5.8	99.7	97.9
Jul-02	6.1	99.7	98.0
Aug-02	5.1	100.0	97.6
Sep-02	6.2	99.6	98.9
Oct-02	5.6	100.0	99.5
Nov-02	5.4	100.0	98.3
Dec-02	6.3	98.9	98.4
Jan-03	6.3	96.5	96.4
Feb-03	6.0	99.3	99.3
Mar-03	6.0	99.5	99.3
Apr-03	5.3	99.9	96.7
May-03	4.1	99.3	96.6

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
Jun-03	5.5	100.0	96.8
Jul-03	5.9	99.1	96.9
Aug-03	6.2	97.9	96.4
Sep-03	6.2	99.7	97.9
Oct-03	5.3	99.5	98.9
Nov-03	5.9	100.0	99.9
Dec-03	5.2	99.9	97.7
Jan-04	5.1	99.7	98.5
Feb-04	5.4	99.7	99.1
Mar-04	5.7	96.2	95.7
Apr-04	5.3	99.7	98.5
May-04	4.9	100.0	98.4
Jun-04	6.6	96.8	95.7
Jul-04	5.6	99.2	95.8
Aug-04	5.2	89.1	86.7
Sep-04	4.7	98.9	97.6
Oct-04	5.0	98.4	97.0
Nov-04	5.2	99.9	98.9
Dec-04	5.2	98.1	96.4
Jan-05	5.4	99.9	99.3
Feb-05	5.3	97.9	97.9
Mar-05	5.1	100.0	99.2
Apr-05	5.5	100.0	99.6
May-05	4.5	100.0	97.2
Jun-05	5.5	99.6	98.3
Jul-05	4.8	97.6	95.8
Aug-05	6.1	99.2	98.5
Sep-05	5.2	99.6	98.3
Oct-05	5.2	100.0	96.8
Nov-05	5.5	100.0	98.3
Dec-05	5.5	99.2	96.4
Jan-06	6.2	100.0	99.3
Feb-06	5.7	100.0	98.8
Mar-06	5.3	100.0	98.7
Apr-06	4.9	100.0	96.8
May-06	4.4	100.0	96.4
Jun-06	4.0	100.0	93.8
Jul-06	5.4	99.6	96.0
Aug-06	4.5	99.9	96.2
Sep-06	5.5	99.7	99.7
Oct-06	5.4	99.1	99.1
Nov-06	5.9	94.3	94.3
Dec-06	6.0	98.4	98.4
Jan-07	5.9	94.6	94.6
Feb-07	5.9	99.3	99.3
Mar-07	6.0	99.7	99.7
Apr-07	4.6	97.5	97.5
May-07	6.3	99.6	99.3

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
Jun-07	5.3	99.0	96.0
Jul-07	5.6	98.7	96.6
Aug-07	5.3	98.8	94.2
Sep-07*	5.7	52.9	50.8

* Incomplete month

Table 4.3 Measurements made at Ballarat AWS at a height of 10 m

Turbine type	REpower MM82 2.0 MW	Windtec WT2000sg
Diameter [m]	82	80.42
Hub height [m]	69	69
Rotor speed [rpm]	10 - 20	12 – 19
No. of blades	3	3
Nominal rated power [kW]	2000	2000

Table 5.1 Main parameters of the wind turbines analysed

Wind speed [m/s at hub height]	Electrical power [kW] REpower MM82 2.0 MW
3	0.0
4	64.0
5	159.0
6	314.0
7	511.0
8	767.0
9	1096.0
10	1439.0
11	1700.0
12	1912.0
13	2000.0
14	2000.0
15	2000.0
16	2000.0
17	2000.0
18	2000.0
19	2000.0
20	2000.0
21	2000.0
22	2000.0
23	2000.0
24	2000.0
25	2000.0

Note: Performance for air density 1.225 kg/m^3 and 6-12% turbulence intensity.

Table 5.2 Performance data for the REpower MM82

Wind speed [m/s at hub height]	Electrical power [kW] Windtec WT2000sg
4.0	14.0
4.5	58.0
5.0	111.0
5.5	173.0
6.0	249.0
6.5	338.0
7.0	436.0
7.5	549.0
8.0	683.0
8.5	835.0
9.0	1006.0
9.5	1195.0
10.0	1387.0
10.5	1593.0
11.0	1773.0
11.5	1906.0
12.0	1974.0
12.5	2000.0
13.0	2000.0
13.5	2000.0
14.0	2000.0
14.5	2000.0
15.0	2000.0
15.5	2000.0
16.0	2000.0
16.5	2000.0
17.0	2000.0
17.5	2000.0
18.0	2000.0
18.5	2000.0
19.0	2000.0
19.5	2000.0
20.0	2000.0

Note: Performance for air density 1.225 kg/m^3 and unknown turbulence intensity

Table 5.3 Performance data for the Windtec WT2000sg

Turbine	Easting[1] [m]	Northing[1] [m]	Mean hub-height wind speed[2] [m/s]	Energy output[3] [GWh/annum]	
				Repower MM82	Windtec WT2000sg
T1	245250	5853900	7.7	6.5	6.1
T2	245457	5853817	7.7	6.5	6.1

Notes

1 Co-ordinate system is MGA 94, Zone 55

2 Wind speed at the location of the turbine, not including wake effects

3 Individual turbine output figures include topographic, array and air density adjustments only

Table 5.4 Turbine layout with predicted individual turbine wind speed and energy production

Month	Mean wind speed [m/s]	Wind speed data coverage [%]	Wind direction data coverage [%]
January	7.5	100.0	100.0
February	7.3	100.0	100.0
March	7.8	100.0	100.0
April	6.1	100.0	100.0
May	8.0	100.0	100.0
June	7.7	100.0	100.0
July	7.5	100.0	100.0
August	7.4	100.0	100.0
September	7.4	100.0	100.0
October	7.2	100.0	100.0
November	7.8	100.0	100.0
December	7.6	100.0	100.0
Mean of means	**7.4**		

Table 6.1 Measured monthly and annual mean wind speeds at the Daylesford mast at 51.7 m (2006 to 2007)

Site: **Daylesford mast at 51.7 m** **Period:** **Annual (2006 to 2007)**

Wind Speed (m/s)	Wind Direction (degrees)												No Direction	Total (%)
	0	30	60	90	120	150	180	210	240	270	300	330		
0	+	0.01	+	0.01		0.02		+		+		0.01		0.05
1	0.06	0.05	0.06	0.05	0.05	0.06	0.04	0.03	0.04	0.06	0.05	0.09		0.64
2	0.20	0.14	0.15	0.11	0.19	0.27	0.15	0.14	0.13	0.21	0.25	0.31		2.24
3	0.46	0.22	0.14	0.17	0.29	0.54	0.33	0.31	0.36	0.39	0.56	0.78		4.55
4	0.90	0.44	0.23	0.19	0.45	0.92	0.61	0.64	0.64	0.71	0.85	1.04		7.62
5	1.32	0.75	0.27	0.21	0.66	1.74	1.05	1.00	0.86	0.77	1.03	1.32		10.98
6	1.78	1.07	0.31	0.25	0.55	2.41	1.86	1.19	1.18	0.73	0.85	1.62		13.80
7	2.15	0.96	0.13	0.09	0.53	3.06	2.38	1.22	1.01	0.54	0.81	1.60		14.48
8	2.32	0.65	0.04	0.02	0.35	3.20	2.25	0.77	0.64	0.33	0.74	1.65		12.95
9	1.98	0.49	0.03	0.01	0.17	2.75	1.50	0.38	0.30	0.22	0.57	1.50		9.89
10	1.61	0.27	0.02		0.07	2.82	0.88	0.20	0.15	0.10	0.40	1.48		7.99
11	1.02	0.13	+		0.07	2.41	0.50	0.11	0.08	0.05	0.34	1.22		5.93
12	0.64	0.04			0.04	1.72	0.20	0.05	0.02	0.03	0.18	0.86		3.79
13	0.34	0.01			0.02	1.21	0.11	0.01	+	0.02	0.10	0.45		2.28
14	0.16	0.02			+	0.80	0.06	0.01		0.01	0.04	0.24		1.34
15	0.12	0.01			+	0.43	0.07			+	0.03	0.12		0.79
16	0.05				+	0.21	0.06			0.01	0.01	0.06		0.40
17	0.03					0.07	0.04			+	0.01	0.02		0.17
18	0.03					0.02	0.02				+	0.01		0.07
19	0.01						0.02					+		0.03
20	0.01										+			0.01
21							+			+				+
22														
23														
24														
25 and over														
Total (%)	15.18	5.26	1.37	1.13	3.42	24.67	12.13	6.05	5.42	4.18	6.82	14.36		100.0
Av.Speed (m/s)	7.88	6.54	4.78	4.50	5.80	8.69	7.48	6.28	6.07	5.66	6.63	7.83	0.00	7.43

NB: + indicates non-zero percentage <0.005%, blank indicates zero percentage

Table 6.2 Measured wind speed and direction frequency distribution at the Daylesford mast at 51.7 m

Source of uncertainty	**Wind speed**		**Energy output**		
	[%]	**[m/s]**	**[%]**	**MM82[1] [GWh/annum]**	**WT2000sg[2] [GWh/annum]**
Anemometer accuracy	2.5	0.19			
Variability of 1.0 year period	6.0	0.46			
Overall historical wind speed		**0.50**		1.6	1.6
Substation metering			0.3	0.0	0.0
Wake and topographic calculation			2.0	0.2	0.2
Future wind variability (1 year)	6.0	0.46		1.5	1.5
Future wind variability (10 years)	1.9	0.15		0.5	0.5
Overall energy uncertainty (1 year)				2.2	2.2
Overall energy uncertainty (10 years)				1.7	1.7

Note 1: Sensitivity of net production to wind speed is calculated to be 3.2 GWh/annum/(m/s)
Note 2: Sensitivity of net production to wind speed is calculated to be 3.2 GWh/annum/(m/s)

Table 6.3 Uncertainty in projected energy output

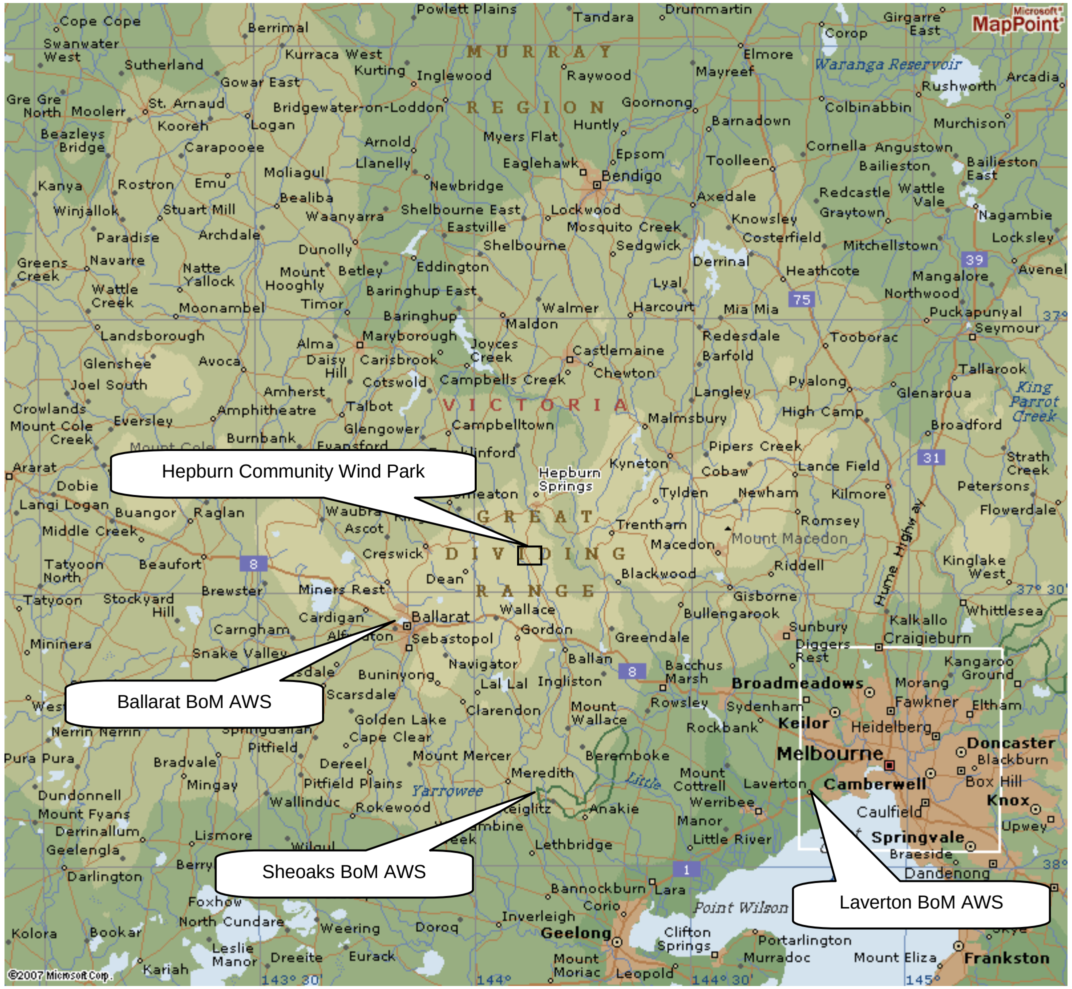

Figure 2.1 Map showing the location of the site and the surrounding BoM stations

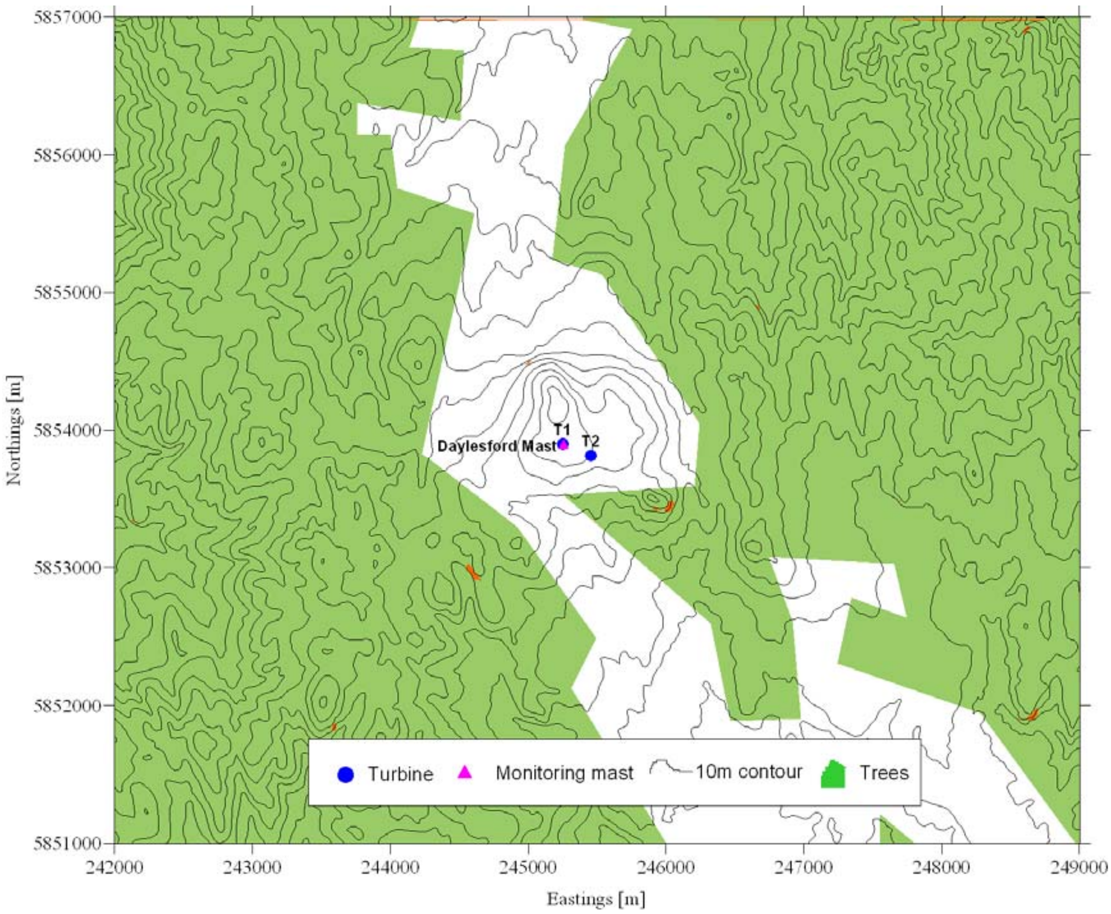

Figure 2.2 Map of the site showing turbine locations and the mast location

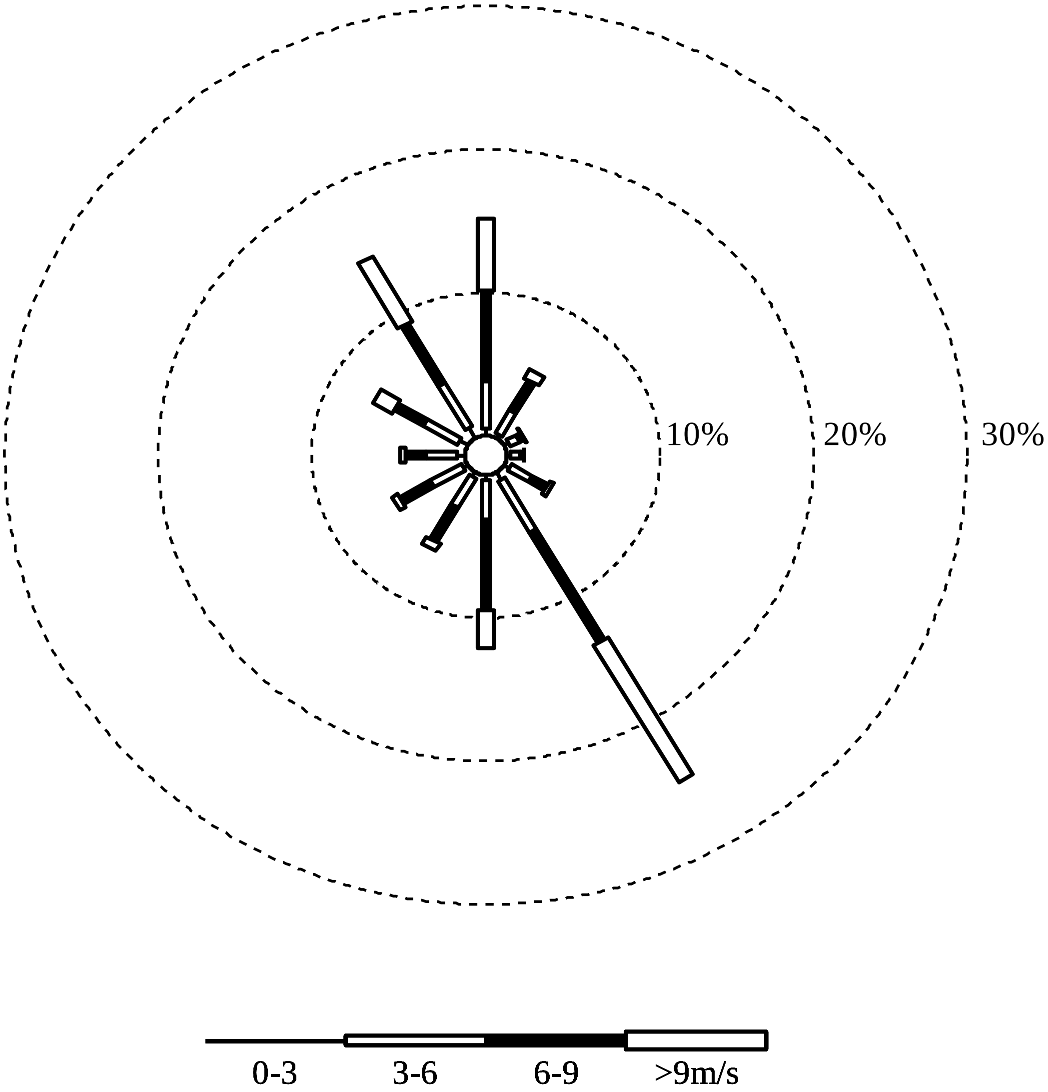

Figure 6.1 Measured wind rose for the Daylesford mast

APPENDIX

Data analysis procedure

1. Site wind speed variations.
2. Projected energy production
3. Confidence analysis
4. References

1 Site wind speed variations

To calculate the variation of mean wind speed over the site, the computer wind flow model, WAsP is used. Details of the model and its validation are given by Troen and Petersen [1].

The inputs to the model are a digitised map of the topography and surface roughness length of the terrain for the site and surrounding area. A digitised map of an area surrounding the site of 29 km x 30 km was supplied by the client. Although this domain size is much larger than the area of the site itself, such an area is necessary since the flow at any point is dictated by the terrain several kilometres upwind.

Wind flow is affected by the roughness of the ground. The surface roughness length of the site and surrounding area has been estimated, as detailed in the main text.

The wind flow calculations were carried out for 30 degree steps in wind direction corresponding to the measured wind rose and results were produced as speed-up factors relative to the mast location for a grid encompassing the site area.

To determine the long-term mean wind speed at any location, the speed-up factor for each wind direction was weighted with the measured probability previously derived for the mast location. All directions were then summed to obtain the long-term mean wind speed at the required location.

2 Projected energy production

The components of the derivation of the wind farm net energy output prediction are listed and described below:

Ideal energy output

The ideal energy production is the theoretical output of the wind farm with the hub height wind speeds at the appropriate mast location applied for all associated turbines. Any density adjustment required due to a difference between the air density at hub height at the reference mast location and that assumed for the turbine power curve is applied as discussed in the main body of the report and included in the ideal energy output.

Topographic and wake effect calculations

The first step in modelling flow through an array of wind turbines is the calculation of the flow in the wake of a single machine. Immediately downstream of the rotor, there is a momentum deficit with respect to free stream conditions, which is equal to the thrust force on the machine. As the flow proceeds downstream, there is a spreading of the wake and recovery to free stream conditions. Turbulent momentum transfer is important in this process.

The model used here, WindFarmer, has been developed by GH and validated using measurements on both full-scale machines and on wind-tunnel models [2, 3, 4].

The model is employed in a scheme which, taking each wind speed and direction in turn calculates the power production of the wind farm. The important parameters used in this process are:

* array layout
* upstream mean wind speed

* ambient turbulence
* wind turbine thrust characteristic
* wind turbine power characteristic
* rotor speed
* topographical speed-up factors from site wind flow calculations

Topographical effects are accounted for in the model using the speed-up factors calculated by the wind flow model described above. Any air density adjustments required due to differences between the hub height air density at the turbine locations and that at the reference mast location is applied as discussed in the main body of the report and included in the topographic effect. The array model is used to calculate the wind speed in the turbine wakes, assuming the terrain is flat, and the wind speed is adjusted by the speed-up factor when the wake reaches a downstream turbine.

Electrical transmission efficiency

A figure of 97 % has been assumed for the electrical efficiency of the wind farm based on GH’s experience of typical wind farm electrical distribution system designs. A formal calculation of the electrical loss should be undertaken when the electrical system has been defined.

Turbine availability

A figure of 97 % has been assumed for turbine availability based on data from modern operational wind farms. However, availability may be a matter of warranty between the owner and the turbine supplier and the assumed figure should be reviewed when the terms of that warranty are clear.

Blade degradation and fouling

The turbine production may be affected by the build up of insects, dirt or ice on the blades. This build up will change the characteristics of the blade and therefore affect the performance of the blades and the turbine output.

An adjustment has been included to allow for lost production due to blade fouling. A figure of 99.5 % has been assumed to be appropriate for the pitch regulated turbines.

High wind hysteresis

This is caused by the turbine cut in and cut out control criteria for high wind speeds. The magnitude of this loss is influenced by three factors.

1 The turbine will cut out when the maximum mean wind speed is exceeded and it will not cut in again until this mean wind speed is below a mean wind speed level lower than the cut out mean wind speed.

2 The turbine will cut out if the instantaneous gust wind speed exceeds a maximum level and the turbine will not cut in until the wind speed drops to a lower value.

3 The accuracy of the calibration of the instruments that are determining the wind characteristics at the turbine.

These three effects will cause the turbine to possibly lose production for some proportion of high mean wind speed occurrences. The magnitude of this lost production has been estimated by GH by repeating the analysis using a power curve with the cut out wind speed reduced by 2.5 m/s for both turbine types.

Substation maintenance

Net wind farm production may be reduced due to the electrical output not being transferred to the grid network while the substation is shutdown for maintenance. A typical figure of 99.8% is assumed in this analysis to represent one day per year of planned maintenance. This is included as scheduled maintenance can not generally be accurately planned to occur on a day with low wind speeds.

Utility downtime

Net wind farm production will be reduced if the grid is not available for the wind farm to output electricity to it. This type of loss must be considered on a site specific basis. It has not been considered in this analysis.

Power curve adjustment

Adjustment to the energy prediction to account for variations in the actual turbine performance in comparison to the supplied power curve. This may be a matter of warranty between the owner and the turbine supplier and the estimated figure should be reviewed when the terms of that warranty are clear and a detailed assessment of this issue has been conducted.

Wind sector management

If wind turbine spacing is close the site conditions may exceed the wind conditions within the wind turbine certification criteria. In these circumstances it may be necessary to shut down some turbines which are closely spaced when the wind direction is parallel to the line of turbines. This issue has not been considered in this analysis.

3 Confidence analysis

There are three categories of uncertainty associated with the site wind speed prediction at the proposed site:

1. There is an uncertainty associated with the measurement accuracy of the anemometers. The instruments used have been individually calibrated and the mounting arrangement of the instruments is to recommended standards. A figure of 2.5 % is assumed here to account for second order effects such as over-speeding, degradation, air density variations and additional turbulence effects.

2. There is an uncertainty associated with the assumption made here that the historical period at the meteorological site is representative of the climate over longer periods. A study of historical wind records indicates a typical variability of 6 % in the annual mean wind speed. This figure is used to define the uncertainty in assuming the long-term mean wind speed is defined by a period approximately 1.0 years in length.

3. Additionally, even if the long-term mean wind speed were perfectly defined there will be variability in future mean wind speeds observed at the wind farm site. The variability in future mean wind speeds is dependant on the period considered. Performance over one and ten years of operation are therefore included in the uncertainty analysis. Account is taken of the future variability of wind speed in the energy confidence analysis but not the wind speed confidence analysis.

It is assumed that the time series of wind speed is random with no systematic trends. Care was taken to ensure that consistency of the reference measurement system and exposure has been maintained over the historical period and no allowance is made for uncertainties arising due to changes in either.

Uncertainties type 1 and 2 from above are added as independent errors on a root-sum-square basis to give the total uncertainty in the site wind speed prediction for the historical period considered.

It is considered here that there are 5 categories of uncertainty in the energy output projection:

1. Long-term mean wind speed dependent uncertainty is derived from the total wind speed uncertainty (types 1 and 2 above) using a factor for the sensitivity of the annual energy output to changes in annual mean wind speed. This sensitivity is derived by a perturbation analysis about the central estimate.

2. Wake and topographic modelling uncertainties. Validation tests of the methods used here, based on full-scale wind farm measurements made at small wind farms have shown that the methods are accurate to 2 % in most cases. For this development an uncertainty in the wake and topographic modelling of 2 % is assumed as the mast is near to the turbine locations.

3. Future wind speed-dependent uncertainties described in 3 above have been derived using the factor for the sensitivity of the annual energy output to changes in annual mean wind speed.

4. Accuracy of the fiscal substation energy meter. An uncertainty of 0.3 % is assumed here based on typical utility meter accuracy.

5. Turbine uncertainties are generally the subject of contract between the developer and turbine supplier and we have therefore made no allowance for them in this work.

Again those uncertainties which are considered are added as independent errors on a root-sum-square basis to give the total uncertainty in the projected energy output.

4 References

1. I Troen and E L Petersen, “European Wind Atlas”, Risø National Laboratory, Denmark, 1989.

2. U Hassan, A G Glendinning and C A Morgan, “ A Wind Tunnel Investigation of the wake structure and machine loads within small wind turbine farms”, Proc of the 12th BWEA Wind Energy Conference, IMechE, 1990.

3. J Højstrup, “Turbulence measurements in a windfarm”, Proc. EWEA Wind Energy Conference, Madrid, 1990.

4. J G Warren et al. "Performance of wind farms in complex terrain", Proc. Of the 17th BWEA Wind Energy Conference, 1995.